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A Common Framework for Integrating Economic and Ecologic Dimensions of Human Ecosystems. III: Policy, Uncertainty, Analysis

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A COMMON FRAMEWORK FOR INTEGRATING THE ECONOMIC AND ECOLOGIC DIMENSIONS OF HUMAN ECOSYSTEMS. III: POLICY, UNCERTAINTY, AND ANALYSIS

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PREFACE

The interactions between agriculture and the environment have emerged as important factors linking the concerns of the agriculturist, the economist, the ecologist, and the sytems analyst. Recognition of their importance has led to the establishment of a task at IIASA to study the environmental problems of agriculture. This task will look at environmental problems at the field level and at the regional and national levels, and it will attempt to provide a framework which can allow insights made at one level to become meaningful at the other as well.

This paper is the third and last in a series designed to examine the interrelationships between the economic and ecological aspects of human ecosystems and to create a framework within which they can be included in analyses of environmental problems of agriculture. It concentrates on the control aspects of the system, emphasizing the treatment and methods for focussing on policy and uncertainty in realistic analyses.

ABSTRACT

Policy and uncertainty are the two aspects of human ecosystems such as agriculture which are the most difficult to capture in models of those systems and which are most important factors in their evolution. Policy may be direct or indirect, and both forms can have strong effects on system behavior. But these effects are not always obvious or clearly interpreted. Policy is generally directed toward specific short-term phenomena, and the momentum and inertia of many parts of agricultural systems are such that it is often impossible to distinguish system-generated from policy-generated change. Likewise, the path of policy implementation through the system as a whole may lead to broader impact and rather different results from those planned by the decision-maker. A multilevel hierarchical view of the human ecosystem shows the natural phenomena of the environment responding to control by farmers and views society as a policy-making system which attempts to guide or control the farmer. This enables the analyst to clarify many of the problems of complexity inherent in analyses of human ecosystems. It provides a common framework for the analysis of economic and ecological (among other) dimensions of the system, and that framework is suitable for technology assessment, policy assessment, and policy design.

A Common Framework for Integrating the Economic and Ecologic Dimensions of Human Ecosystems. III: Policy, Uncertainty, And Analysis

The first two papers in this series (Clapham and Pestel, 1978a, 1978b) have discussed ways of looking at agricultural systems as examples of human ecosystems in general. They have suggested treating them as multilevel hierarchical systems in which the natural stratum comprises those basic biological, chemical, and physical phenomena which occur in all ecosystems, and the middle strata comprise the management functions of society and of the individual (Figure 1). This view of the system allows the relationships which unify the ecological and economic components to be considered in single analytical framework. It is based on the idea that the entire system in the real world is a legitimate and single entity which must often be considered as a unit in order to make sensible and meaningful analyses. Its purpose is to provide a way of managing human ecosystems in a creative, efficient and sustainable fashion. Its focus is on its base, the phenomena and the problems of the natural stratum which confer its basic character. But in fact, the system is a whole, and a focus on the base cannot reduce the importance of the decisions and perceptions in the middle which lead society to mold the natural stratum toward its own ends.

The multilevel view of human ecosystems is an analytical tool which can help to understand the system and to design and test management strategies for it. It enables the analyst to treat the management process as a set of phenomena with very different characteristics and analytical requirements from those of the natural stratum. The strata are coupled by the linkage shown in Figure 2: Information from the higher stratum acts to control the lower, which changes in response. The higher stratum monitors this response and adapts its control to better approach the overall goals of the system. The most important

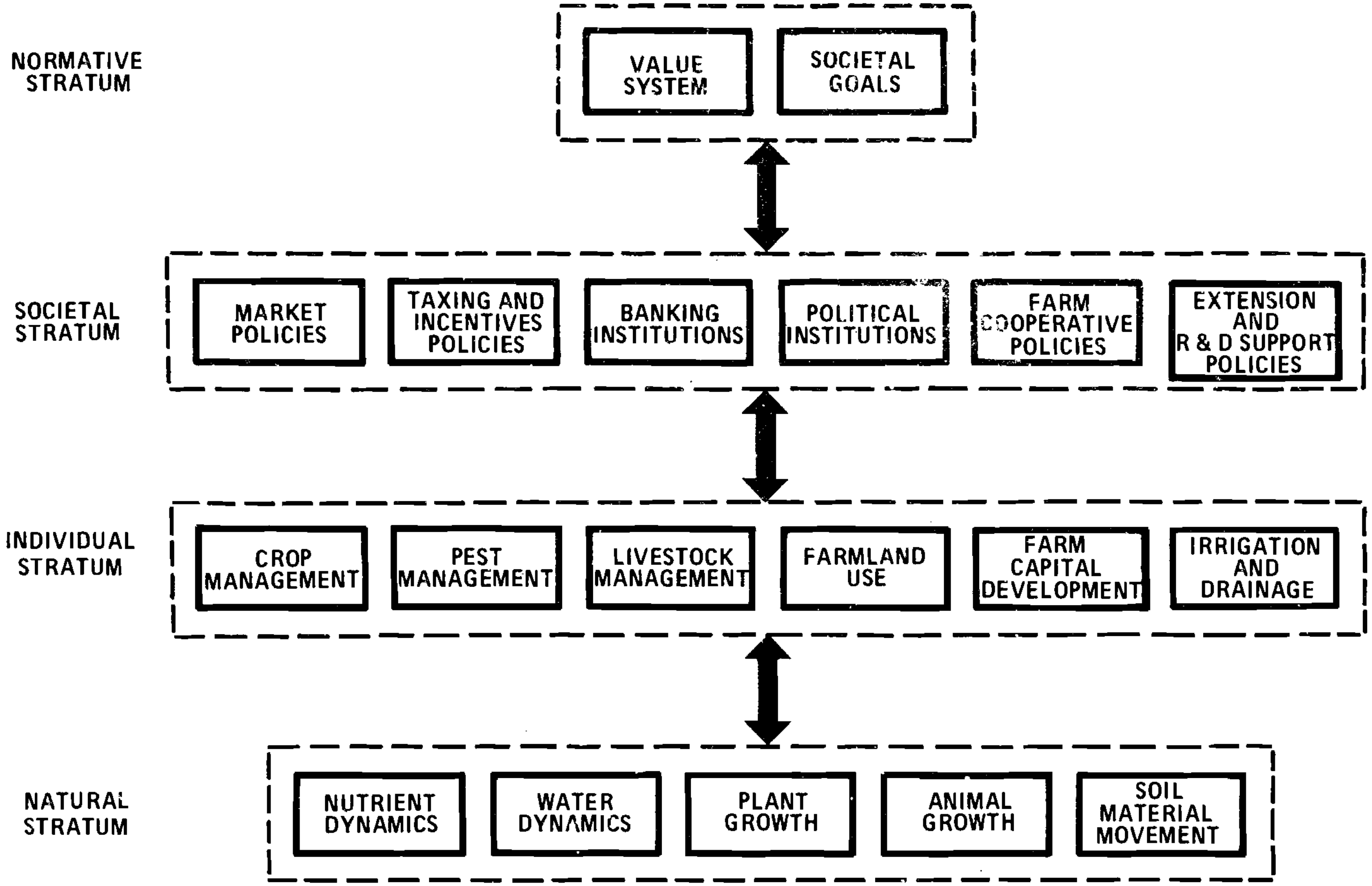

Figure 1. Agriculture as a multilevel hierarchical system. Only those parts of the society directly involved with agriculture as shown. All processes or phenomena within a stratum are assumed to affect each other.

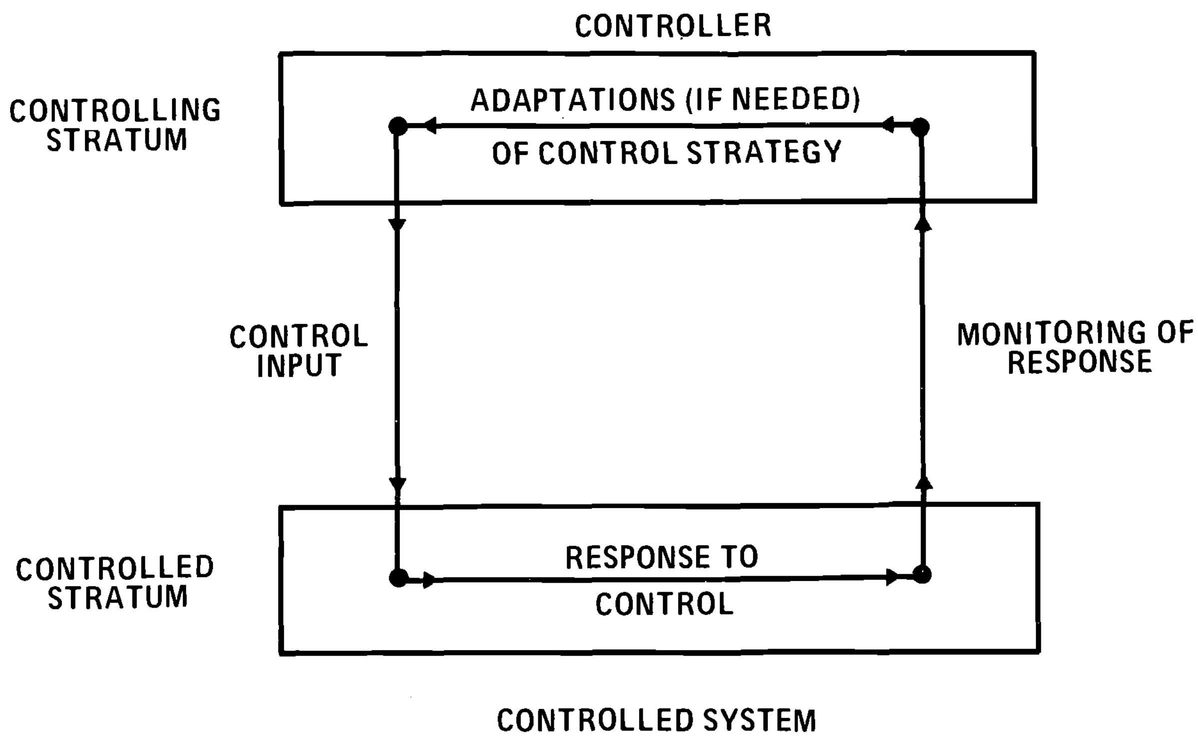

Figure 2. Interactions between a controlling and controlled systems.

function of the analysis of human ecosystems is to understand the system so that the needs of society can be met most effectively. In a previous paper (Clapham and Pestel, 1978b), we have discussed the treatment of the natural stratum. In this paper, we shall address the role of the managerial strata and their couplings with the natural stratum.

The human ecosystem is characterized by the natural stratum. Its dimensions in space and the extent of its coverage are fixed by the natural stratum. But the higher strata extend beyond these limits. Even the farmer, the herder, the fisherman, and the other individuals whose behavior characterizes the individual stratum and who exert direct influence on the natural stratum are concerned with non-ecological phenomena as well. And institutions on the societal stratum encompass many sectors which have virtually nothing to do with ecosystems. This means that the view summarized in Figure 1 is a narrow one. It focuses on the relationships between the natural stratum and the forces controlling it. Nevertheless, if the purpose of our formalized construct is to aid in management planning, it must ultimately also deal with management activities of society which are inherently top-down and which necessarily encompass all major motive forces of the society, of which ecological concerns are a fraction.

For the remainder of this discussion, we shall concentrate on agriculture as typical of human ecosystems in general. We shall also act as though the analysis of human ecosystems involved the use of mathematical models. This is not necessarily the case, of course, but since such models are the most formal form of analysis, our conclusions can be generalized relatively easily to any other form of analysis that might be used in the same framework.

We can distinguish two lines of concern for the higher strata in a management-oriented view of human ecosystems: policy and uncertainty. Policy is a mechanism which can be used by society to make use of or to change the uses of degrees of freedom. Policies may be imposed for myriad reasons by any number of significant factors, or actors in the system. A policy which affects a given human ecosystem such as agriculture may be directed toward agriculture itself, or it may be directed toward an entirely different set of concerns so that the impact on agriculture is secondary. In the former case, it might in principle be possible to endogenize policy into a model, but only if the policy represented a highly predictable response to changes in the system state depending on rules which were already well known and which could be applied with known or no time lag. But in the second case, it is obviously impossible to endogenize such a policy into a model of human ecosystems. Even if the system's behavior is well understood and the rules are well known, the information needed to specify the response and the "handles" that would be needed to consider it are not present.

In the same way, uncertainty affects the number of degrees of freedom available to the society, but perhaps in an opposite way. On one hand, the uncertainty of ecological phenomena such as weather, climate, and so forth must be included at least implicitly in any reasonable analysis of the behavior of a human ecosystem. Indeed, it must be considered in several ways. Of course there is the manifestation of the uncertainty and its effect on production. But there is also the way that individual farmers account and plan for the probable range of uncertainty that they face between the beginning of the cropping cycle and harvest. They may or may not be able to consider the probability of extreme weather conditions or related "disasters". On another level, society must also be aware of these uncertainties. This is not because society (e.g. the government) is to plant the fields; its time horizons and outlooks are clearly very different from those of the individual farmer. Rather, agricultural production is so basic to most societies that government must respond to crisis situations.

This paper will discuss the roles of policy and uncertainty in the modeling approach to management design for human ecosystems. Because any given human ecosystem such as agriculture is only a part of the larger society and its associated resource base, it will also be necessary to deal with the nature of the system boundary and role of actors and subsystems not included within the definition of the human ecosystem. Finally, it will discuss the treatment of policy and uncertainty in the context of a formal analysis of a human ecosystem. To some degree, these factors can be endogenized into the model. More often they must be considered external to it, either as scenarios or in model interpretation.

POLICY DIMENSIONS OF HUMAN ECOSYSTEMS

Policy is the mechanism by which the higher strata of a society attempt to reach certain goals, to create targets or pathways for implementing targets, or to remove objectionable behavior, or to correct the developmental trajectory of the society. Policies are generally relatively specific in their goals. This is due partially to the decentralization of authority and responsibility characteristic of decision-making structures in most societies. No complex system can be understood in sufficient detail at any one point in time by any decision-maker to recognize how a simultaneous correction of all its aspects will lead to an improvement in conditions. In general, a policy is directed towards a single problem. But because of the complexity of most societal systems, a change brought about by one policy will probably have impacts on other parts of the system which were not intended by the policy-maker. This is normal and to be anticipated, and the dynamics of the policy process in the real world are designed to work toward an improvement in the situation by a stepwise, iterative, satisficing procedure.

The policy process can be viewed in terms of actors, institutions, instruments, and actions. The relationship between these is discussed in greater detail by Clapham, Pestel, and Arnaszus (1978). Basically, however, actors are specific people or groups of people who can make decisions affecting the society or who are affected by these decisions and who may respond to them in some way. Most actors do not act by themselves: they operate in terms of institutions which shape, constrain, and influence the kinds of actions which are possible. The existence of institutions is a critical part of the policy process, as certain actions may be impossible without the right institutional framework. Even the most creative and well-intentioned policy-maker (actor) may be frustrated in his desire to reach certain goals when he cannot implement a decision even when he has the power on paper to make it, because the institutional framework does not exist to carry it out. The instruments of policy are those parts of the system which an actor (decision-maker) can control directly. These may be economic instruments such as taxing policies or pricing policies, they may be land use policies (e.g., land reform), research and development subsidies and resource allocations, propaganda on mass media, etc. The actions of the actor are those specific constellations of instrument settings which can be implemented by him.

Policy decisions can affect ecosystems in a great many ways. Land use is subject to constraints imposed by policy-makers, such as acreage allotments for various crops or prohibitions on certain uses, as well as by incentives or taxing policies which lead to certain uses which normally would not result if the market were not interfered with. Decision-makers in national or international agencies set priorities on development of new seeds, machinery, cropping technologies, and so forth. Virtually every aspect of the control of the natural stratum by higher strata is somehow directed or constrained by policy, and the role of policy in changing the interactions between society and the natural stratum must obviously be considered in any reasonable analysis of an agricultural system.

From the viewpoint of policy, the most important strata are the societal and individual strata on which decisions are made and reactions are felt. The normative stratum provides the constraints within which policy can act, as well as the goals towards which policy is directed. The natural stratum responds to policy inputs by assuming a characteristic structure which can be monitored by the higher strata. All of the actors in society occupy the middle two strata. On the lower of these are those actors (the farmer, the fisherman, and the livestock manager) who actually interact directly with the natural stratum. Also included are environmental groups, hiking groups, park departments, public-road builders, watershed managers, public water supply authorities, and myriad others. All direct users of land, water, or air resources also occupy the individual stratum. On the societal stratum exist those institutions and activities which are directed towards overseeing the structure of the society or influencing the interactions between various segments. Here are governments, foreign investors, investment institutions, research institutions, financial institutions, etc. The instruments of the individual stratum are relatively simple. They are the direct control inputs onto the natural stratum. In the case of agriculture, these have already been discussed adequately by Clapham and Pestel (1978b). The actions available to the societal stratum commonly relate to resource allocations between various sectors of the economy, incentives, prohibitions, regulations, etc. An elaboration of the actions available to different sectors of a particular society in the context of agricultural ecosystem management can be seen in Pestel, Helmer, Fischer, and Clapham (1978).

Agriculture must coexist with other economic sectors in any country. Decisions within other sectors of the economy may have very profound effects on agricultural systems. Much more than the natural stratum, the rules that govern the higher strata, especially the social decision-making stratum, are cultural phenomena under the influence or control of policies made by the most important actors in the society. These actors are generally governments, both national and local. But governments are not always the most important actors, especially in developing countries. Foreign governments, foundations, industries, and research organizations may have a considerable influence on the behavior of an economy or structure of a human ecosystem.

In any given country there are certain rules which can be taken for granted. While they will not be the same for all countries, the individual country has certain "ways of doing things". These structural interrelationships can be assumed for a realistic analysis. But there are other fields of activity in which there are no rules, or those rules which exist are violated.

Direct Policy Intervention in a Human Ecosystem

Direct policy interventions in agriculture are those designed to affect it. They include the decisions made by individuals who interact directly with the natural stratum, as well as by society insofar as it attempts to alter or control the interrelationships between actors on the individual stratum and the natural stratum. They comprise the broad range of decisions that would normally be described as agricultural policy and refer to all of the measures taken by the middle two strata whose primary intent is to affect the natural stratum, either directly or indirectly through the individual stratum. It includes a broad range of objectives, as well as a broad range of instruments.

Timing and Phasing of Direct Policy Inputs to a Human Ecosystem

The direct policy interventions involve information passage across stratum boundaries. An analysis of policy thus requires considering both the passage of information from the stratum generating the policy and the response of the stratum on which it is imposed. As discussed in Clapham and Pestel (1978a), the typical interaction between two strata is that shown in Figure 2, in which the controlling stratum makes some control input and waits for the response of the controlled stratum. After the controller has accumulated sufficient information that he can assess the impact and effectiveness of his input, he can adjust it so that the system's behavior better meets his requirements. In most systems where there is an obvious controller (i.e., a person) and a controlled system (generally an abiotic device such as a machine), this notion causes no problem. The responses of the controlled stratum are relatively clear and they are fast enough that the trajectory of system evolution can be assessed readily and revisions of control, if feasible, can be implemented.

But human ecosystems differ from machines in some important ways. The natural stratum is characterized by components which may have very long time constants. These subsystems show considerable inertia, while other parts respond very quickly. At the same time, agricultural systems are exploitation ecosystems (in the sense of Clapham, 1976) of considerable economic importance to many countries. That is, there is a close and substantial feedback interaction between the natural and controlling strata. Management of the natural stratum is directed toward meeting production requirements within a cropping cycle, and the natural stratum is closely monitored to assure that inputs needed to meet these production goals can be made, within the capabilities of the individual manager. The result is that agricultural systems in their entirety can be viewed as economic entities, and decisions are often made only with regard to the short-run behavior of the system. This does not mean that the long-term aspects of the system are not present or not recognized: it simply means that the management of the system is not oriented towards them. But the long-run behavior of the high-inertia subsystems on the natural stratum can best be regarded as a response to the integral of all inputs over a relatively long period of time roughly equivalent to that of the "time constant" of the subsystem in question.

From here stems the main dilemma in human-ecosystem management for the policy-maker. Most of the decision-making structure of society is legitimately directed toward the system's short-term behavior. But it is obvious that public policy at all levels should also be directed toward maintaining the short-term behavior in a productive and healthy fashion over the longer term period. But because the time constants of some subsystems of the natural stratum are so long, it is not always possible to sort out the effect of policy from that of the sheer momentum of the system. The result may be a great deal of observation and data, but very little understanding of the processes or relationships involved, so that identification of viable policy and management alternatives is difficult or even impossible. But because the observable system state is a function of so many things in such a complex way, the level of understanding which is required depends on careful experiments, regional observation, and experience, among other things. Any individual set of data is bound to be misleading, and the synthesis of the many potentially available data sets needed for thorough understanding is likely to be difficult and extremely time-consuming. Nevertheless, a great deal of understanding, especially of the dynamics of the natural stratum, is essential for accurately assessing the interactions between the natural and social strata. Indeed this may be the only way of assessing the long-term behavior of the overall system in a satisfactory way.

And this assessment is critical. There are many examples of responses to the short-term dynamics of agricultural systems which might have seemed economically appropriate at the time, but which have led to major problems because the long-term dynamics were ignored or unknown. The best example of this is the whole phenomenon of desertification (United Nations, 1977) or the dustbowl of the southwestern United States during the 1930s. In both of these instances, the local farmers and the national institutions reacted with all of the knowledge and power at their disposal to use what resources they had for maximally productive purposes. The results were overgrazing because of the maintenance of livestock herds which were far too big and massive soil losses because adequate vegetation cover was not maintained to retard normal wind erosion.

In extreme cases such as desertification, deterioration of the natural-stratum resource base is all but irreversible. The mismatches in phasing between actions directed toward observable short-term behavior on one hand and the long-term momentum of the natural stratum on the other, coupled with our general lack of knowledge in this exceedingly complex area, render meaningful policy decisions very difficult at best. And in the vulnerable areas of the world, notably the tropics and subtropics, as well as arid lands in general, it is the most precarious situations which result in actions to which the system is most sensitive. The question of environmental policy in human ecosystems thus boils down, at least in one important dimension, to the design of policies which are not only intrinsically multi-objective but which also consider phenomena acting on very different time-scales, some of which may be quite ill-defined.

Inclusion of Direct Policy Interventions in Formal Analysis

There are clearly two problems in including the direct policy interventions in formal analyses in human ecosystems. The first is to specify the policy itself; the second is to document its impact through the system. It is sometimes possible to include policy generation in a model of a human ecosystem, but only if the rules of societal response are well understood. Most policies of any importance are not so simple, and they must be entered as scenarios (Clapham, Pestel, and Arnaszus, 1978). Likewise, changes in behavior by strategically placed actors are all but impossible to endogenize adequately and need to be specified by scenarios.

Some scenario methods are quite adequate for our purposes (see, for example, Carr, 1976; Knauer, 1978). But what is not so clear is how to follow the ramifications of policy implementation through a model. Policy evolution represents a dynamic change in the important controls which society places on the system. As such, it represents a powerful mechanism by which the state space of the system can shift to a position not represented by known time-series data, so that empirical validation of a policy-driven model is not possible. Credibility in such a model requires that the structural specifications and parameter estimations of the system be based on the best data, partial theory, and judgement available, and that the outputs of the model can be corroborated by an experienced observer. In addition, the model should be tested against actual real-world policy implementations.

Indirect Policy Intervention in a Human Ecosystem

The indirect policy interventions in human ecosystems are those which are not intentionally directed toward the human ecosystem itself, but which affect it indirectly and sometimes unintentionally. An example in recent years is the effect of the rise in oil prices on food production in many developing countries. The oil price rise was a direct policy intervention directed toward developed countries. It was not intended to condemn people in poor countries to starve. But it had that effect by causing an increase in the price of fertilizer, of which petroleum is an important feedstock, and of fuel to drive irrigation pumps.

A view such as that shown in Figure 1 indeed represents a very large portion of the system and is significantly more comprehensive than the customary view. But the real world is much more inclusive, and the process of abstraction requires a number of simplifications to make analysis feasible. For example, our view of feedback has thus far been fairly simple. The notion of control-respond-monitor-adapt is appropriate for interstratal feedback where the actor-controller also monitors the system's response and can adapt to it. But there are often numerous anomalies in the system which must be considered, and it often happens that several actors are adapting simultaneously to the responses of a controlled system and with several different (and perhaps conflicting) views and actions.

For a better view of the indirect policy dimensions of human ecosystems, it is meaningful to look at the system shown in Figure 3. The "only" difference between Figure 3 and Figure 1 is that Figure 3 includes more actors on the individual stratum who can interact with the natural stratum. The natural stratum

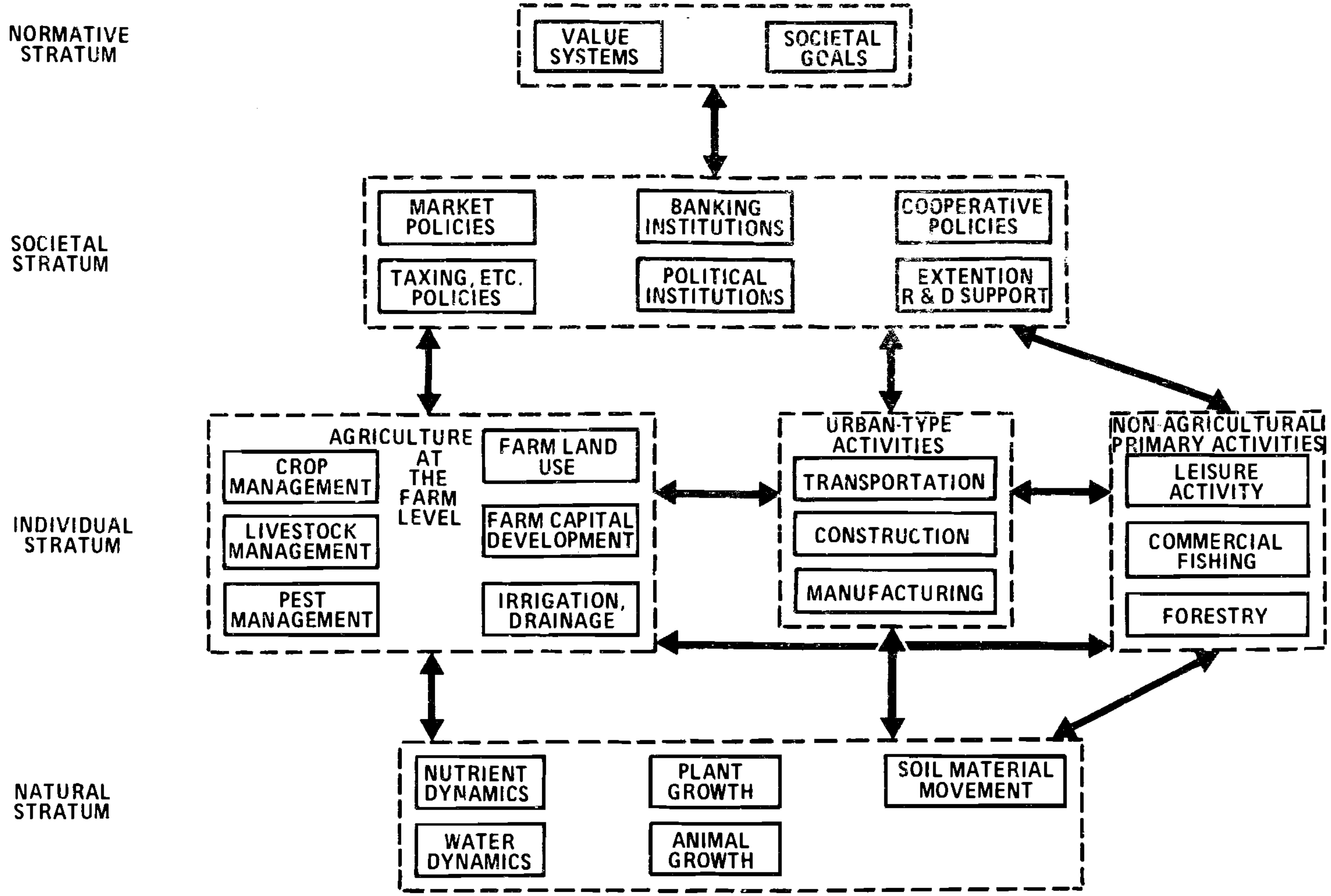

Figure 3. A multilevel hierarchical view of a society showing agriculture, as in figure 1, along with other sectors of the society. The decomposition into strata is the same as that in Figure 1. The compositions of the natural and normative strata are identical to those of figure 1; the composition of the societal stratum differs slightly in that it relates to more factors acting at the individual level.

with which they interact, however, can be viewed in exactly the same way in the two views, and the societal stratum is also essentially identical for both. The only difference is that policies not directed explicitly toward the human ecosystem of Figure 1 can be shown explicitly in Figure 3.

Figure 3 is, perhaps, a more realistic way of looking at the system, as all parts of the individual stratum do interact with natural stratum, and the societal decision-making apparatus can be viewed as allocating resources between different actors, regardless of their relationship with the natural stratum. But in such a view it is also clear that feedback may have not only the simple route shown in Figure 2 but also a much more complicated route such as the one shown in Figure 4.

Furthermore, some or all of the multilevel feedback routes of Figure 4 may not be present in a definition of a human ecosystem as shown in Figure 1, since one or more of the actors may not be considered in that view. And yet just as we are limited in the detail and complexity of a model which we can understand and build, the relationships that we do not consider in a formal construct do not disappear when we reenter the real world.

It makes a lot of sense to think of human ecosystems like agriculture as being appropriately represented by the human ecosystem view of Figure 1. But some of the most important impacts on agriculture are those engendered by some policy or general regulation imposed by the societal stratum and directed towards a completely different part of the economy. The oil price rise is only one example. In such cases, the effect on agriculture may not even be monitored as such. Important changes, especially in the natural stratum, may be overlooked by society, especially if its monitoring procedures concentrate only on the sectors which were the targets of the regulation. In the real world, the ramifications of policy decisions throughout the system are often broad and far-reaching, and no analysis of or attempt to manage any one subsystem can ignore others which might seem

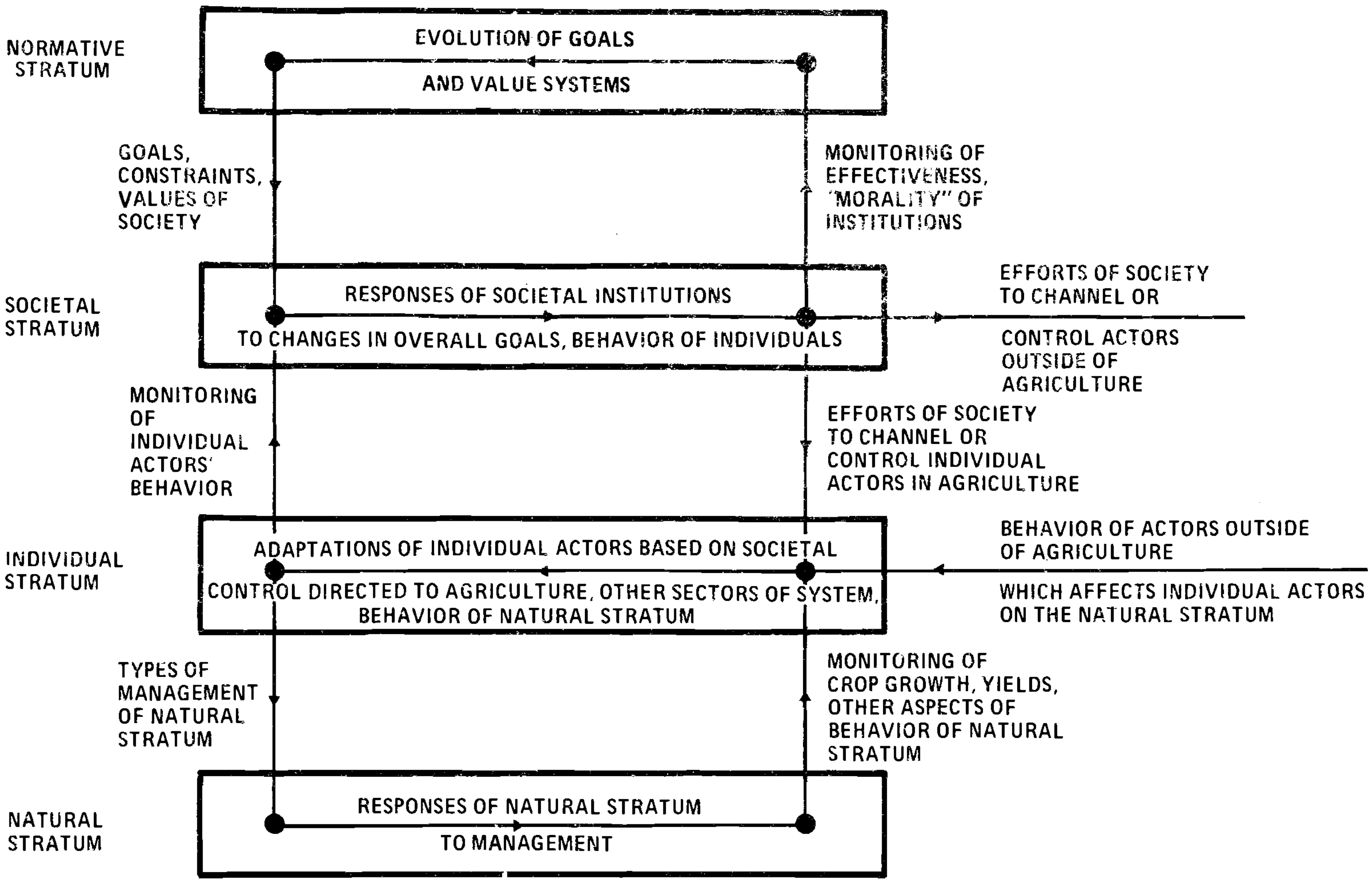

Figure 4. Interactions among strata within a human ecosystem as a whole.

only loosely related but which are important target sectors for public policy. In all cases, there are information pathways in the real world which may be significant for specific human ecosystems and which cannot be included explicitly in the analytical framework for valid reasons. If they are significant, they must be accounted for in another way.

These pathways may generate, depending on their timing and phasing, a series of responses by farmers (or other managers of human ecosystems) which appear inconsistent with their real requirements with regard to the natural stratum but which are, in fact, consistent with the larger information flow patterns of the real system. A good example of this is the often dominant role of the fertilizer salesman in farmers' choices of types and use rates for fertilizers. On the other hand, the larger information flow patterns may also represent forces within the system which lead to breakdowns of the natural stratum even when the requirements of the farming population are consistent with the needs of the natural stratum. A good example of this is the increasing pressure being put on traditional cultivators and pastoralists in many countries to increase their production for the cash market. Normally, the activities of these peoples would be essentially in balance with the natural stratum. But as population and especially economic pressure both grow, their agricultural pursuits become too powerful, and the effect on the natural stratum may range from severe deterioration to desertification.

Closure and Analysis of the "Real" Problems of Human Ecosystems

All the problems characteristic of direct policy inputs are also found with the indirect policy inputs. There are others as well, since the actors on the individual stratum must contend with a set of policies and regulations which are not directed towards their needs or capabilities as farmers and which change with the larger system. The analyst must not only assess the long-run behavior of the high-inertia subsystems on the natural stratum, he must also assess how this system is affected by a constantly changing "environment", generated in this case by the effects of policy directed towards other sectors than those considered in the agricultural system.

But it is in the indirect effects that the importance of understanding the system become most clear. When there is a conflict between different actors on the individual stratum, so that some accommodation must be found between them, the only alternatives are to adopt a relatively arbitrary set of standards for behavior or to agree on standards which are related to the particular ecosystem in question and which can make use of its dynamic properties. A common example is with regard to agricultural water pollution. In order to reduce eutrophication and siltation, environmental protection boards may set standards of fertilizer and/or land use on farmers. Such standards may not take account of the fact that nutrient runoff is a function of soil and crop characteristics, and that the worst problems typically have many potential solutions if the characteristics of this specific site are considered carefully. Arbitrary standards are probably quite inefficient in general, from the viewpoint of the best use of the resources represented by the human ecosystem, as they represent a foreclosure of options which might otherwise be available.

UNCERTAINTY DIMENSIONS TO HUMAN ECOSYSTEMS

Most analyses of human ecosystems are not, in fact, directly interested in the environment. One worries about environment rather because Mother Earth is perceived as a fickle being who cannot be depended upon to deliver constant weather or indestructible soils. She imposes uncertainty on the analyst as well as the manager in a way which may be stochastic or correlated to an unknown driving variable in an unknown fashion. In some ways, uncertainty is analogous to policy in that it represents the "use" of degrees of freedom by the system to change the overall results. In this case, of course, the degrees of freedom are not "used" by society: they are "taken" by the environment itself and rendered inaccessible to society in the process.

This is by no means the only type of uncertainty, however. There are also changes engendered by society which are not foreseen by the decision maker but which affect the parameters he would like to depend on. This is "system-generated uncertainty" which is a problem that can be circumvented only by a thorough understanding of the rules governing the system behavior in a changing policy environment. Both interpretations of uncertainty are important, depending on the particular situation.

Some kinds of uncertainty are measurable, at least in principle. These might be inserted into a system as a stochastic variable so that its effect could be studied in a Monte Carlo or similar sort of fashion. The most important variables of this sort are weather inputs, both because weather can be treated exogenously and also because the distributions of weather-related parameters can be measured quite accurately. Indeed these are some of the most measurable of variables, because weather records commonly go back far longer than the other variables preferred in economic models. There are other variables such as soil erosion or pest attack which might be regarded as uncertain in some sense, but these are complex variables which cannot be measured very easily. They may be as important as weather fluctuations, and under some circumstances even more so. They can easily (at least in principle) be viewed in a scenario sense, and introduced into most economic models. But they are inherently difficult to measure, and measurements are likely to be quite inexact.

In both of these cases, uncertainty serves as an input to the system. We have assumed that their role in the analysis was to provide a realistic context within which to assess the responses of the ecosystem to those forms of control which cross interstratal boundaries. But uncertainty can also be studied in its own right, and this may be more useful at our present state of knowledge than using it as a basis of scenarios. This is especially true of the system-generated sort. If the ultimate point of analyses of human ecosystems such as agriculture is to help design policies for dealing with them, then a relatively simple analysis to explicate the sources of"noise" being generated by the system would be exceedingly useful and, most likely, much cheaper than a full-scale analysis. This would develop an understanding of system-generated uncertainty so that it can be treated in the policy design process in an appropriately dynamic fashion rather than as a purely stochastic variable. This type of uncertainty is dynamic, and to treat it as purely stochastic would be misleading.

SHAPE OF AN ANALYSIS OF A HUMAN ECOSYSTEM

Many kinds of analyses of human ecosystems might be done for equally many valid reasons. Perhaps the most important are those which deal with the uncertainty dimensions of the system relative to the time-scale mismatches of different parts of the system. A multilevel analysis of the sort discussed here which considers both policy and uncertainty in an explicit and integrated fashion is perhaps the only way in which these differences in time horizon can be seen and for which appropriate policies and management techniques can be designed. Such an analysis might take several forms. Its goal might be to design an optimal policy to maximize agricultural production, profit, or some other simple objective function on a long-term sustainable basis. In practice, we feel that this is exceedingly unlikely, because the non-linearities and combinatorial problems of a system as complex as even a simple human ecosystem are overwhelming.

It is more likely that a scenario approach such as described in Clapham, Pestel and Arnaszus (1978) will provide a more efficient satisficing type of approach to policy design considering environmental realities. Indeed, a satisficing scenario approach is probably the only way in which the realities of technological change can be implemented in such a model. The alternative is a system which considers technological innovation in some simple fashion. This is the way it is handled, for example, in econometric models which assume technological change. But it is implicit in such models that technological change is directed toward specific goals, generally convergent with those of the model itself. In the example of the econometric model, this is generally profit, production, or a related factor. The assumption that technological change is directed toward goals convergent with welfare maximization is probably reasonable if technological innovation is market-directed, if long-term environmental momentum does not upset the direction imposed by the market on agricultural innovations and technologies, and if a meaningful welfare function for the society can be designed.

But in vulnerable areas, especially those in which the long-term momentum is significant and must be considered, policy must override the short-term market forces and which will assure stability within the technological limits of the society. "Appropriate technologies" will often have to be developed for specific instances. Indeed, the whole notion of appropriate technology suggests that it must be developed and directed by policy-oriented means which may not be related directly to the normal objective functions of profit or welfare maximization. Examples of this are small-scale machines being developed for use in vulnerable areas of developing countries by governments and international agricultural institutes. The precise nature of the technological innovations and the patterns of their diffusion throughout the system cannot be estimated on the basis of past performance, because they are new, small in scale, and not predictable in the economic sense. Nevertheless, they are very important in some areas, and they will both cause and solve problems.

CONCLUSIONS

Analyses are designed for specific purposes by specific analysts, and generally with specific clients or users in mind. There is thus no such thing as a general system which will meet all needs or anything more general than a broad philosophical approach within which specific needs can be realized. The multi-level view of human ecosystems, such as agricultural systems, presented in this series of papers represents an extraordinarily powerful framework for the organization and implementation of ecosystem analysis. Within it, the needs of the manager and the decision-maker can be addressed in the same context as the long-term behavior and momentum of the natural environment. Some of the concerns are very broad; others are restricted in their scope. Precisely how any given analysis will be undertaken depends, of course, on the analyst and his needs. We have presented one mechanism for linking management and the "practical" considerations which face the higher strata with the basic phenomena on the natural stratum.

Even the most difficult cases, such as the vulnerable systems of tropical, subtropical, arid, and semi-arid zones, can be analyzed in such a way that the environmental consequences of various activities can be understood. A wide range of policies and styles of technological development and diffusion can be considered, as well as policy design in other areas dealing with the human ecosystem as a whole. The uncertainties of the system can also be understood and considered throughout. Not only is it possible to construct a common framework for the ecologic and economic dimensions of human ecosystems; it is possible to use that framework for designing analyses for technology assessment, policy assessment, and policy design.

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